BABAR-PROC-04/133
SLAC-PUB-10875

Review of Recent BaBar Results

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Proceedings of: 2nd International Conference in High-Energy Physics: HEP MAD 04, 26 Sep - 4 Oct 2004, Antananarivo, Madagascar

1 Abstract

We present a review of recent results from BaBar experiment. BaBar detector has collected about 256 millions of $B\overline{B}$ events at PEP-II, the asymmetric e^+e^- collider located at SLAC running at the $\Upsilon(4S)$ resonance. We have studied CP violation in B mesons, observing the first evidence of direct CP violation in B meson decays and measured CP asymmetries relevant for the determination of the angles of the CKM Unitarity Triangle. BaBar physics program covers many other topics, including measurements of CKM matrix elements, charm physics, and search for new physics processes.

2 Introduction

BaBar experiment runs at the PEP-II asymmetric B-factory located at SLAC laboratories. The center of mass energy corresponds to the mass of the $\Upsilon(4S)$ resonance which decays predominantly into pairs of B and anti-B mesons. The experiment has recorded until July 31st 2004 an integrated luminosity of about 244 fb^{-1}, with a peak luminosity of 9.2×10^{33} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

A detailed description of the detector can be found elsewhere [1]. A silicon vertex tracker (SVT) consisting of five layers and a drift chamber (DCH) with 40 stereo layers provide the detection of charged particles whose momentum is measured in a 1.5-T solenoidal magnetic field. The energy loss measurement ($\mathrm{d}E/\mathrm{d}x$) in the tracking detectors contributes to the charged particle identification. A detector of internally reflected Cherenkov radiation (DIRC) is the main subsystem used for charged hadron

identification. A finely segmented CsI(Tl) electromagnetic calorimeter (EMC) is used to measure electron and photon energy. The instrumented flux return (IFR) segmented with Resistive Place Chambers provides muon identification. Neutral hadrons (K_L) are identified in the EMC and the IFR.

3 CP Violation

Violation of the CP symmetry can be explained in the Standard Model with a non eliminable phase in the Cabibbo-Cobayashi-Maskawa quark mixing matrix. It has been first observed in the neutral Kaon system as the effect of CP violation in mixing. This type of CP violation is expected to be small ($\sim 10^{-3} \div 10^{-4}$) in the neutral B-meson system. A large violation is possible in the Standard Model both as direct CP violation and as time-dependent CP violation in the interference between mixing and decay.

3.1 Direct CP violation

A significant direct CP violation may arise in the decay $B^0 \to K^-\pi^+$ from the interference between the tree and penguin diagrams. We have reconstructed B^0 decaying to $K^-\pi^+$ and its charge conjugate mode; B meson decays are identified using the kinematical variables:

$$\Delta E = E_B^* - \sqrt{s}/2 \ , \tag{1}$$

$$m_{ES} = \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2} \ , \tag{2}$$

where $\sqrt{s}$ is the center of mass energy, E_B^* is reconstructed B meson energy in the center of mass system, and the four-momenta $\mathbf{p}_B$ and $(E_i, \mathbf{p}_i)$ of the reconstructed B and the initial state respectively are defined in the laboratory frame. Correctly reconstructed B mesons show a two-dimensional peak around m_{ES} equal to the B mass and $\Delta E = 0$. The DIRC information and dE/dx are used to identify charged Kaons and pions. The direct CP violation is measured as:

$$\mathcal{A}_{K\pi} = \frac{n_{K^-\pi^+} - n_{K^+\pi^-}}{n_{K^-\pi^+} + n_{K^+\pi^-}} \ . \tag{3}$$

We measure $\mathcal{A}_{K\pi} = -0.133 \pm 0.030(\text{stat.}) \pm 0.009(\text{syst.})$ [2], which corresponds to a 4.2σ deviation from zero. As a comparison, in the decay $B^+ \to K^+\pi^0$, which may also exhibit a large asymmetry [3] we measure an asymmetry of $0.09 \pm 0.09(\text{stat.}) \pm 0.01(\text{syst.})$ [4].

3.2 Time-dependent CP violation and $\sin 2\beta$

CP violation in the interference between mixing and decay can be observed as a time-dependent oscillation of the CP asymmetry. The amplitude of the oscillation in charmonium decay modes provides a theoretically clean determination of the parameter $\sin 2\beta$ of the unitarity triangle. Combining the measurements in a number of $(c\overline{c})K^0$ final states, with both K_S and K_L, BaBar has measured [5]:

$$\sin 2\beta = 0.722 \pm 0.040(\text{stat.}) \pm 0.023(\text{syst.}) \ . \tag{4}$$

Using the cleanest modes with decays containing K_S, we can observe no evidence of a direct CP violation contribution from the compatibility with measurement of the parameter $|\lambda| = |\overline{A}/A|$, where A is the B meson decay amplitude, with the unity:

$$|\lambda| = 0.950 \pm 0.031(\text{stat.}) \pm 0.013(\text{syst.}) \ . \tag{5}$$

An independent constraint on $\cos 2\beta$ can be obtained from the decay $B \rightarrow J/\psi K\pi$ using the interference between the $K\pi$ S-wave and P-wave amplitudes from $K^* \rightarrow K\pi$ decays. We can constrain the sign of $\cos 2\beta$ to be positive with a confidence level of 86% [6].

The Standard Model predicts other B decay modes, dominated by a single penguin amplitude, such as $B^0 \rightarrow \phi K^0_S$ and $B^0 \rightarrow K^0_S\pi^0$, to have a time-dependent CP asymmetry of magnitude $\sin 2\beta$. A discrepancy of the CP asymmetry measurements in such channels from the value of $\sin 2\beta$ measured in charmonium modes may be due to the presence of non standard particles running in the penguin diagram loops. BaBar has measured such time-dependent amplitudes in a number of modes [7]. The results are reported in Table 1. The measured values tend to be systematically lower than the value of $\sin 2\beta$ measured with charmonium modes, their average being about 2.7 standard deviations lower. The analysis of the data that will be collected in the forthcoming runs is necessary to confirm or not such discrepancy.

3.3 Measurements of α

The most promising way of measuring $\sin 2\alpha$ is through the time-dependent CP asymmetry of $b \rightarrow u$ tree-level transitions, such as in $B \rightarrow \pi^+\pi^-$. Such decay suffer from the pollution of penguin contributions that, unlike the case of charmonium modes, don't have the same week phase as the tree diagram. In the case of a negligible penguin contribution the time-dependent CP asymmetry would have a sinusoidal oscillation with an amplitude equal to $\sin 2\alpha$; with the introduction of penguin contribution, such amplitude is changed into $\sqrt{1-C}\sin 2\alpha_{eff}$, where C is the amplitude of a cosine term which is proportional to $\sin\delta$, where δ is the relative penguin strong phase with respect to tree amplitude.

Decay mode	CP amplitude
ϕK^0	$0.50 \pm 0.25^{+0.07}_{-0.04}$
$\eta' K^0_S$	$0.27 \pm 0.14 \pm 0.030$
$f^0 K^0_S$	$0.95^{+0.23}_{-0.32} \pm 0.10$
$\pi^0 K^0_S$	$0.35^{+030}_{-0.33} \pm 0.04$
$K^+K^-K^0_S$	$0.55 \pm 0.22 \pm 0.12$
s-penguin average	0.42 ± 0.10
$(c\overline{c})$ average	0.726 ± 0.037

Table 1: "$\sin 2\beta$" measurements in different channels. When two errors are quoted they refer to the statistical and systematics contribution respectively.

We have determined [8] the sine and cosine term amplitudes of the time-dependent oscillation of the CP-asymmetry for $B \to \pi^+\pi^-$ to be:

$$\mathcal{S}_{\pi^+\pi^-} = -0.30 \pm 0.17(\text{stat.}) \pm 0.03(\text{syst.}) \ , \tag{6}$$

$$\mathcal{C}_{\pi^+\pi^-} = -0.09 \pm 0.15(\text{stat.}) \pm 0.04(\text{syst.}) \ . \tag{7}$$

From the study of the complementary isospin channels $B^\pm \to \pi^\pm\pi^0$ and $B^0 \to \pi^0\pi^0$ it is possible to determine an upper bound to $|\alpha - \alpha_{eff}|$. We measure [10] a branching fraction $\mathcal{B}(B^\pm \to \pi^\pm\pi^0) = (5.80 \pm 0.06(\text{stat.}) \pm 0.40(\text{syst.})) \times 10^{-6}$, and the direct CP asymmetry for the same channel is $\mathcal{A}_{\pi^\pm\pi^0} = -0.01 \pm 0.10(\text{stat.}) \pm 0.02(\text{syst.})$. For the $\pi^0\pi^0$ channel we measure [11] $\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.17 \pm 0.32(\text{stat.}) \pm 0.10(\text{syst.})) \times 10^{-6}$, and a cosine amplitude for the time-dependent CP asymmetry to be: $\mathcal{C}_{\pi^0\pi^0} = -0.12 \pm 0.56 \pm 0.06$. Those measurements allow, using Ref. [9] , to set the upper limit, at 90% confidence level:

$$|\alpha - \alpha_{eff}| < 35^\circ \ . \tag{8}$$

A more favourable situation has been found for the measurement of α with $B^0 \to \rho^+\rho^-$. This channel requires an angular analysis of the final state, because it is not a CP eigenstate. From a measurement of the polarization it turns out that the state is completely longitudinally polarized: $f_{long} = 1.00 \pm 0.02$, which corresponds to a pure CP=1 state. From an update using 277×10^6 $B\overline{B}$ events of the analysis from Ref. [12]., the time-dependent analysis yields the measurement of the sine and cosine amplitudes:

$$\mathcal{S}_{long} = -0.19 \pm (\text{stat.}) 0.33 \pm 0.11(\text{syst.}) \ , \tag{9}$$

$$\mathcal{C}_{long} = -0.23 \pm (\text{stat.}) 0.24 \pm 0.14(\text{syst.}) \ , \tag{10}$$

Where the last limit has been updated with 122×10^6 $B\overline{B}$ events [13] with respect to Ref. [14]. The measurements of the branching fractions of the corresponding isospin

channels are:

$$\begin{aligned}\mathcal{B}(B^{\pm} \to \rho^{\pm}\rho^{0}) &= (22.5^{+5.7}_{-5.4}(\text{stat.}) \pm 5.8(\text{syst.})) \times 10^{-6} , & (11)\\ \mathcal{B}(B^{0} \to \rho^{0}\rho^{0}) &< 1.1 \times 10^{-6}(90\%\text{C.L.}) . & (12)\end{aligned}$$

Using (9, 10) we can determine α to be:

$$\alpha = (96 \pm 10(\text{stat.}) \pm 4(\text{syst.}) \pm 11(\text{peng.}))^{\circ} , \tag{13}$$

where the upper limit to the penguin uncertainty has been determined from (11, 12) using the Grossman-Quinn bound [15].

3.4 Studies for the measurement of γ

Different approaches[16] have been suggested to determine the unitarity angle γ using the interference a $b \to c$ and a $b \to u$ transition, whose relative phase is related to γ, in the decays $B^- \to D^{(*)0}K^-, \overline{D}^{(*)0}K^-$ with subsequent decays into final states accessible to both charmed meson and anti-meson. One of the main problem from the experimental point of view is that the size of the CP asymmetries involved depend on the ratio of the favoured and the color suppressed decays:

$$r_B^{(*)} = \left| \frac{\mathcal{A}(B^- \to \overline{D}^{(*)0}K^-)}{\mathcal{A}(B^- \to D^{(*)0}K^-)} \right| , \tag{14}$$

which is expected to be in the range $0.1 \div 0.3$. Using the method suggested by Atwood, Dunietz and Soni, we have studied the subsequent decays of D^0 and $\overline{D}^0$ in $K^+\pi^-$, where one can assume as input[17]:

$$r_D = \left| \frac{\mathcal{A}(D^0 \to K^+\pi^-)}{\mathcal{A}(D^0 \to K^-\pi^+)} \right| = 0.060 \pm 0.003 . \tag{15}$$

No signal has been observed [18], allowing to set the limits $r_B < 0.23$ and $r_B^* < 0.16$ at the 90% confidence level.

Another approach [19] to the measurement of gamma involves the Dalitz analysis of the three-body decay $D^0 \to K_S\pi^-\pi^+$. This method has the advantage to involve the entire resonant substructure of the three-body decay, with the interference of both Cabibbo-allowed and doubly Cabibbo-suppressed amplitudes. The results of the analysis[20] may be expressed as the limits: $r_B < 0.24$ and $r_B^* < 0.18$ at the 90% confidence level. The constraint on γ is still rather limited: $\gamma = (88 \pm 41(\text{stat.}) \pm 19(\text{syst.}) \pm 10(\text{mod.}))^{\circ}$, the latter error reflecting the uncertainty in the Dalitz model.

The decays modes $B^0 \to D^{(*)-}\pi^+, D^{(*)-}\rho^+$ receive contributions from a favoured $b \to c$ and a suppressed $b \to u$ amplitudes, whose interference is related to $\sin(2\beta +$

γ), that could be measured from the time-dependent CP asymmetry. The limiting experimental factors are the small amount of the asymmetry. We have studied $B^0 \to D^{(*)-}\pi^+$ with both full reconstruction of the final state [21] and partial reconstruction, with the $D^{(*)-}$ being tagged with the identification of the soft pion only [22].

4 Semileptonic B decays

4.1 Measurements of $|V_{cb}|$

We have measured the exclusive branching fraction of the decay $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell$, whose magnitude is proportional to $|V_{cb}|$. The branching fraction has been determined to be, averaging over $\ell = e$, μ [23]:

$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell) = (4.90 \pm 0.07(\text{stat.})^{+0.36}_{-0.35}(\text{syst.})) \times 10^{-3} \quad . \tag{16}$$

The differential decay rate can be measured as a function of w, the relativistic boost of the D^{*+} in rest frame of the B^0. In the limit of infinite b-quark and c-quark masses, the differential decay rate can be determined from a single Isgur-Wise function [24]:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}w} \propto \mathcal{G}(w)\mathcal{F}(w)^2|V_{cb}|^2 \ . \tag{17}$$

The value of the form factors $\mathcal{G}(w)\mathcal{F}(w)^2$ at $w = 1$ can be predicted using lattice calculations [26]. The differential rate has been fitted to the experimental data using a Taylor expansion, and the result of the fit extrapolated to the value $w = 1$, providing the following measurement of $|V_{cb}|$:

$$|Vcb| = (38.7 \pm 0.3(\text{stat.}) \pm 1.7(\text{syst.})^{+1.5}_{-1.3}(\text{th.})) \times 10^{-3} \ . \tag{18}$$

Another more accurate measurement of $|V_{cb}|$ can be obtained extracting from the distributions of hadron mass and lepton energy spectra the moments in inclusive decays $\overline{B} \to X_c\ell^-\overline{\nu}_\ell$, defined as:

$$M_0 = \frac{\int_{x_{cut}}^{\infty} \mathrm{d}\Gamma}{\Gamma_B} \ , M_1 = \frac{\int_{x_{cut}}^{\infty} x\mathrm{d}\Gamma}{\int_{x_{cut}}^{\infty} \mathrm{d}\Gamma} \ , M_n = \frac{\int_{x_{cut}}^{\infty} (x - M_1)^n\mathrm{d}\Gamma}{\int_{x_{cut}}^{\infty} \mathrm{d}\Gamma} \ , (n = 2, 3) \ , \tag{19}$$

where the variable x is either the hadron mass or the lepton energy. The moments defined in (19) can be related via Operator Product Expansions (OPE) [27] to fundamental parameters of the Standard Model including as the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$ and the heavy quark masses m_b and m_c. The fit of the dependency of the moments on the applied cut to the hadron mass or the lepton energy [28] leads to the determination of a number of observables. In particular, we determine [29]:

$$\mathcal{B}(b \to c\ell\nu) = (10.61 \pm 0.16(\text{exp.}) \pm 0.06(\text{th., HQE}))\% \ , \tag{20}$$
$$|V_{cb}| = (41.4 \pm 0.4(\text{exp.}) \pm 0.4(\text{HQE}) \pm 0.6(\text{th.})) \times 10^{-3} \ . \tag{21}$$

The errors refer to the experimental, HQE, and additional theoretical uncertainties. We could have with the same fit precise determination of the b and c quark masses:

$$m_b(1\text{GeV}) = (4.61 \pm 0.05(\text{exp.}) \pm 0.04(\text{HQE}) \pm 0.02(\text{th.}))\text{GeV}/c^2 \ , \quad (22)$$
$$m_c(1\text{GeV}) = (1.18 \pm 0.07(\text{exp.}) \pm 0.06(\text{HQE}) \pm 0.02(\text{th.}))\text{GeV}/c^2 \ . \quad (23)$$

The c quark mass measurement is in very good agreement with the theoretical prediction using QCD Spectral Sum Riles (QSSR) from the measured $D(0^-)$ and $D_s(0^-)$ masses: $\overline{m}_c(m_c) = 1.13^{+0.08}_{-0.04}$ GeV/c^2 [30].

4.2 Measurements of $|V_{ub}|$

We have measured $|V_{ub}|$ from the study of inclusive electron spectrum in $B \to X_u e\nu$ decays near the kinematic limit accessible to $B \to X_c e\nu$ decays. The partial branching fraction has been measured in electron momentum range from 2.0 to 2.6 GeV/c and has been extrapolated to the full momentum range using [31] a previous measurements of the inclusive photon spectrum in $B \to X_s\gamma$ decays [32]. The result is [33]:

$$|V_{ub}| = (3.94 \pm 0.25(exp) \pm 0.37 \pm (f_u) \pm 0.19(th)) \times 10^{-3} \ , \quad (24)$$

where the first error is the sum in quadrature of the statistical and systematic uncertainties, the second refers to the uncertainty of the determination of the fraction f_u of the inclusive electron spectrum in the range from 2.0 to 2.6 GeV/c, and the third error is due to theoretical uncertainties in the QCD corrections and the b-quark mass.

Further measurements of $|V_{ub}|$ can be obtained from the studies of exclusive $b \to u\ell\nu$ decay channels. BaBar has developed a novel technique to approach such decays, by completely reconstructing the decay of the companion B meson, thus significantly reducing the background to the reconstruction of the semileptonic decay. The price to pay is the reduction of statistics, that will anyway be overcome with the increase of collected data sample, when the statistical sensitivity will approach the systematic limit. Preliminary measurements of exclusive branching fractions are [34]:

$$\mathcal{B}(B^0 \to \pi^-\ell^+\nu) = (1.08 \pm 0.28(\text{stat.}) \pm 0.16(\text{syst.})) \times 10^{-4} \ , \quad (25)$$
$$\mathcal{B}(B^+ \to \pi^0\ell^+\nu) = (0.91 \pm 0.28(\text{stat.}) \pm 0.14(\text{syst.})) \times 10^{-4} \ , \quad (26)$$
$$\mathcal{B}(B^0 \to \rho^-\ell^+\nu) = (2.57 \pm 0.52(\text{stat.}) \pm 0.59(\text{syst.})) \times 10^{-4} \ . \quad (27)$$

The extraction of $|V_{ub}|$ is in progress.

5 Channels probing new physics

B decays provide a probe to explore new physics processes which could arise with the exchange of virtual non-Standard particles.

5.1 Radiative penguin decays

Radiative $b \to s\gamma$ and $b \to d\gamma$ decays proceed in the Standard Model via electromagnetic penguin diagrams. New particles could replace the W and quarks exchanges in the penguin loop producing deviation in the rate and CP asymmetries with respect to the Standard Model predictions. While the world average of the decay rate of $b \to s\gamma$ ($(3.3 \pm 0.4) \times 10^{-4}$ [35]), in agreement with the Standard Model prediction [36], has reached a level of uncertainty comparable to the error on the theoretical prediction, the $b \to d\gamma$ are at the limit of discovery according to the Standard Model prediction. BaBar has set the following 90% confidence level limits [37]:

$$\mathcal{B}(B \to \rho^+\gamma) \ < \ 1.8 \times 10^{-6} \ , \tag{28}$$

$$\mathcal{B}(B \to \rho^0\gamma) \ < \ 0.4 \times 10^{-6} \ , \tag{29}$$

$$\mathcal{B}(B \to \omega\gamma) \ < \ 1.0 \times 10^{-6} \ , \tag{30}$$

that can be combined into:

$$\mathcal{B}(B \to (\rho/\omega)\gamma) < 1.2 \times 10^{-6} \ . \tag{31}$$

The study of CP asymmetry of $b \to s\gamma$ has been performed on a number of inclusive final states containing one charged or neutral kaon and one to three pions [38]. The measured asymmetry leads to:

$$\mathcal{A}_{CP}(b \to s\gamma) = 0.025 \pm 0.050(\text{stat.}) \pm 0.015(\text{syst.}) \ , \tag{32}$$

to be compared to a Standard Model prediction of less than 1% [39]. In the exclusive channel $B \to K^*\gamma$ the CP asymmetry is constrained in the range:

$$-0.074 < \mathcal{A}_{CP}(B \to K^*\gamma) < 0.049 \ , \tag{33}$$

at 90% confidence level.

5.2 Search for pentaquarks

Recent experimental studies have been reported observations of new exotic baryon resonances with narrow width which could be interpreted as states composite of five quarks. In particular the Θ^+ with a mass around 1540 MeVc^2 has been reported in Ref. [41], the Ξ^{--} and Ξ^0, both with masses around 1862 MeVc^2 have been reported in Ref. [42] and the Θ_c^0 with a mass of 3099 MeVc^2 has been reported in Ref. [43]. Several theoretical models have been proposed to explain such states [44].

Pentaquark states may be produced in e^+e^- collisions as well, and the very large statistics collected by BaBar may provide a way to probe pentaquark production down to very low branching fractions. We have searched for the Θ^{*++} in the decay

$B^+ \to \Theta^{*++}\overline{p}$ where $\Theta^{*++} \to pK^+$ using 81 fb^{-1} of data [45] and we set an upper limit on the branching fraction to be $1.5 \div 3.3 \times 10^{-7}$, at 90% confidence level, depending on the mass of the Θ^{*++}, which has been assumed to vary from 1.43 to 2.00 GeV/c^2. We have also performed an inclusive search for strange pentaquark production using 123 fb^{-1} of data. Different decay channels have been studied, assuming the quark content of the $\Theta^+(1540)$ to be $udud\overline{s}$, and of the $\Xi^{--}(1860)$ and $\Xi^0(1860)$ to be $dsds\overline{u}$ and $uss(u\overline{u} + d\overline{d})$ respectively. In addition we have searched for other members of the antidecuplet and corresponding octet that would complete the five-quark model for such states. Though we found very clear signal for known barions, demonstrating the experimental sensitivity to narrow resonances in the mass range of interest, we found no evidence for the production of pentaquark states. We set a number of limits on their production cross sections as functions their of center of mass momentum. The complete list of results can be found in Ref. [46]; the limits are at the level of $10^{-4} \div 10^{-5}$ per event, depending on the width assumed, valid for any narrow state with a mass close to the range $1540 \div 1860$ MeVc^2.

6 Study of charmed meson spectroscopy

In 2003 BaBar discovered the $D^*_{sJ}(2317)^+$ meson [47], confirmed by other observations [48, 49]. Subsequently the $D_{sJ}(2460)^+$ meson was also observed [48, 50]. The two discoveries reawakened interest in charmed meson spectroscopy. The spectroscopy of $c\overline{s}$ states can be described in the limit of large charm-quark mass [51]. Under that limit, the sum of the orbital and spin momenta $\overrightarrow{j} = \overrightarrow{l} + \overrightarrow{s}$ is conserved. The positive-parity P-wave states have $j = 3/2$ or $j = 1/2$. Combining those two states with the spin of the heavy quark, we have, from the state with $j = 3/2$, the possible values of the total angular momentum $J = 2$ and $J = 1$, and from the state with $j = 1/2$ the values $J = 1$ and $J = 0$. The members of the $j = 3/2$ doublet are expected to have small width [52], the state $J^P = 2^+$ being identified to be the $D^*_{sJ}(2573)^+$, while the state $J^P = 1^+$ is identified with the $D_{s1}(2536)^+$. The observed narrow width of the $D^*_{sJ}(2317)^+$ and $D_{sJ}(2460)^+$, which are below the kinematical threshold of the decay by kaon emission, are in contradictions with some prediction of states with masses between 2.4 and 2.6 GeV/c^2 [52, 53], which would also have a large widths because of the dominant decays to $D^{(*)}K$. A review of recent the theoretical approaches towards the computation of the masses of the new states, including the hypothesis of unconventional multiquark states can be found in Ref. [54]. Different models also provide prediction for decay branching ratios. There is hence experimental interest in the determination of the properties of the newly discovered states. Detailed studies of their decays can now provide more accurate information. Using the decay $D^*_{sJ}(2317)^+ \to D^+_s \pi^0$ we obtain the mass measurement [56]:

$$m(D^*_{sJ}(2317)^+) = 2318.9 \pm 0.3(\text{stat.}) \pm 0.9(\text{syst.}) \text{ MeV}/c^2 \ . \quad (34)$$

Averaging the measurements from the decays of the $D_{sJ}(2460)^+$ to $D_s^+\gamma$, $D_s^+\pi^0\gamma$ and $D_s^+\pi^+\pi^-$ we obtain:

$$m(D_{sJ}(2460)^+) = 2459.4 \pm 0.4(\text{stat.}) \pm 1.2(\text{syst.})\ \text{MeV}/c^2\ . \quad (35)$$

The relative branching fractions of the decays under study are also measured with an uncertainty of the order of $15 \div 20\%$.

The study of the distribution of helicity angle of the decay $D_{sJ}(2460)^+ \to D_s^+\gamma$ in decays $B \to D_{sJ}(2460)^+\overline{D}^{(*)}$ can be used to obtain information on the $D_{sJ}(2460)^+$ spin J [57]. BaBar observations favours the hypothesis of a $J^P = 1^+$ state, excluding a $J^P = 2^+$ state. A recent calculation [55], using QCD spectral sum rules, which are less affected by large $1/m_c$ corrections than HQET, also including radiative corrections, provides the estimate $m(D_s^*(1^+)) = (2440 \pm 113)$ MeV/c^2, in agreement with our measurement of the $D_{sJ}(2460)^+$ mass, supporting a $J^P = 1^+$ assignment.

7 Acknowledgements

We are grateful for the extraordinary contributions of our PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The success of this project also relies critically on the expertise and dedication of the computing organizations that support BABAR. The collaborating institutions wish to thank SLAC for its support and the kind hospitality extended to them. This work is supported by the US Department of Energy and National Science Foundation, the Natural Sciences and Engineering Research Council (Canada), Institute of High Energy Physics (China), the Commissariat à l' Energie Atomique and Institut National de Physique Nucléaire et de Physique des Particules (France), the Bundesministerium für Bildung und Forschung and Deutsche Forschungsgemeinschaft (Germany), the Istituto Nazionale di Fisica Nucleare (Italy), the Foundation for Fundamental Research on Matter (The Netherlands), the Research Council of Norway, the Ministry of Science and Technology of the Russian Federation, and the Particle Physics and Astronomy Research Council (United Kingdom). Individuals have received support from CONACyT (Mexico), the A. P. Sloan Foundation, the Research Corporation, and the Alexander von Humboldt Foundation.

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